CLINICAL ORAL IMPLANTS RESEARCH

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Digital versus conventional implant impressions for edentulous patients: accuracy outcomes

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Abstract

Purpose: To compare the accuracy of digital and conventional impression techniques for completely edentulous patients and to determine the effect of different variables on the accuracy outcomes.

Materials and methods: A stone cast of an edentulous mandible with five implants was fabricated to serve as master cast (control) for both implant- and abutment-level impressions. Digital impressions (n = 10) were taken with an intraoral optical scanner (TRIOS, 3shape, Denmark) after connecting polymer scan bodies. For the conventional polyether impressions of the master cast, a splinted and a non-splinted technique were used for implant-level and abutment-level impressions (4 cast groups, n = 10 each). Master casts and conventional impression casts were digitized with an extraoral high-resolution scanner (IScan D103i, Imetric, Courgenay, Switzerland) to obtain digital volumes. Standard tessellation language (STL) datasets from the five groups of digital and conventional impressions were superimposed with the STL dataset from the master cast to assess the 3D (global) deviations. To compare the master cast with digital and conventional impressions at the implant level, analysis of variance (ANOVA) and Scheffe's *post hoc* test was used, while Wilcoxon's rank-sum test was used for testing the difference between abutment-level conventional impressions.

Results: Significant 3D deviations ($P < 0.001$) were found between Group II (non-splinted, implant level) and control. No significant differences were found between Groups I (splinted, implant level), III (digital, implant level), IV (splinted, abutment level), and V (non-splinted, abutment level) compared with the control. Implant angulation up to 15° did not affect the 3D accuracy of implant impressions ($P > 0.001$).

Conclusion: Digital implant impressions are as accurate as conventional implant impressions. The splinted, implant-level impression technique is more accurate than the non-splinted one for completely edentulous patients, whereas there was no difference in the accuracy at the abutment level. The implant angulation up to 15° did not affect the accuracy of implant impressions.

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Passive fit of implant-fixed complete dental prosthesis (IFCDP) depends on the accuracy of the implant cast, which is directly dependent on the accuracy of the impression technique (Jemt & Hjalmarsson 2012; Papaspyridakos & Lal 2013). There are several clinical and laboratory variables that affect the accuracy of an implant cast, namely impression and pouring techniques, impression material and die stone properties, machining tolerance of prosthetic components, and implant angulation and depth (Ma et al. 1997; Papaspyridakos et al. 2014a).

The first and most significant step is the impression procedure. Different implant impression techniques have been used to generate a definitive cast that will ensure the accurate clinical fit of IFCDPs. A recent systematic review on the accuracy of implant impressions showed that the splinted technique is superior to the non-splinted option for both partially and completely edentulous patients (Papaspyridakos et al. 2014a). The necessity for splinting the impression copings has been advocated in several studies, while others have shown no difference (Papaspyridakos et al. 2012). It has also been reported that open-tray techniques are superior to the closed-tray version for completely edentulous patients, but no difference was identified for partially edentulous patients (Papaspyridakos et al. 2014a). The diverse results from some previous *in vitro* studies may be partially explained by the machining tolerance of components, by the differences in methods for accuracy measurements, and by improvements in dental materials.

The effect of implant angulation and connection type on the accuracy of implant casts generated with various impression techniques for edentulous jaws has not been fully investigated yet. For completely edentulous patients, six *in vitro* and three clinical studies reported on accuracy outcomes with angulated implants (Aguilar et al. 2010; Papaspyridakos et al. 2011, 2012; Mpikos et al. 2012; Ongul et al. 2012; Stimmelmayr et al. 2012a,b; Akalin et al. 2013; Gimenez et al. 2015). The three clinical studies did not focus on the details of implant angulation but reported that the splinted technique was clinically more accurate than non-splinted or closed-tray techniques when angulated implants were involved (Papaspyridakos et al. 2011, 2012; Stimmelmayr et al. 2012b), whereas the six *in vitro* studies showed mixed results. Hence, there is insufficient guidance for choosing impression techniques for different implant angulations in completely edentulous cases. Additionally, the effect of implant connection type (internal connection vs external connection) on the accuracy of implant impressions for fully edentulous jaws has not been investigated sufficiently.

Digital implant dentistry has transformed the relationship between dentist and dental laboratory. As a part of this trend, digital impressions have been a significant contributor to this changing relationship. Digital impression scanners eliminate tray selection, dispensing and setting of impression materials, disinfection, and impression shipping to the laboratory, while patient comfort may be an additional advantage (Christensen 2009; Ender & Mehl 2013; Patzelt et al. 2014). Intraoral scanners may increase efficiency, because it is possible to digitally send a digital impression to the laboratory, rather than sending a conventional impression via regular mail. The digital impression file can be stored electronically, which eliminates space management issues, supports a paper-free practice, and contributes to efficient record keeping. Limitations pertain to the additional cost of purchasing an intraoral scanner and the learning curve for adjusting to the new treatment modality.

A growing number of edentulous patients are seeking implant prosthodontic treatment. The application of computer-guided surgery and CAD/CAM technology in implant prosthodontics has aided in simplifying a number of treatment steps (Papaspyridakos et al. 2014a, 2014b). No data exist on the accuracy of digital implant impressions for completely edentulous jaws. Research on digital implant impressions is limited to a few case reports (Lin et al. 2013, 2014; Moreno et al. 2013). Therefore, a study assessing the performance and accuracy of digital impressions compared to conventional impressions for completely edentulous patients would contribute to clinically validate this new cutting-edge technology.

The purposes of this study were (i) to test whether or not digital implant impressions are more accurate than conventional implant impressions in completely edentulous patients and (ii) to test whether or not the implant angulation or the implant connection type (internal connection vs abutment-level connection) affects the accuracy of implant impressions and casts of completely edentulous patients. The null hypothesis of this investigation was that digital impressions exhibit similar accuracy as conventional implant impressions.

Materials and methods

A mandibular cast with five interforaminal internal connection implants (Bone Level RC, Straumann, Basel, Switzerland) was fabricated to simulate a common clinical situation. The median three implants were parallel to each other, whereas the distal left implant had an angulation of 10° and the distal right of 15°. This cast was fabricated in clear acrylic resin in a specialized facility (Model Plus Inc, Grayslake, Il).

Master cast fabrication

As the clear acrylic resin cast could not be digitally scanned and digitized, a stone master cast was fabricated to serve as control. One screw-retained metal framework (laser-welded titanium bars to titanium abutments) was fabricated on this clear acrylic resin cast at the abutment level (Multi-Base RC; Straumann). A pickup impression of the master implant framework was taken with polyether impression material (3M ESPE; Impregum, St. Paul, MN, USA). Implant analogs were then connected to the framework inside the pickup impression, which was poured with low expansion (0.09%) type IV die stone (Silky Rock; Whipmix Corp, Louisville, KY, USA) 2 h after impression taking (Del'Acqua et al. 2008). The stone was mixed under vacuum with distilled water, and an initial pour of stone up to the middle of the analogs was carried out. After 30 min, the second pour of vacuum-mixed die stone was added. The stone cast was allowed to set for 1 h, as per manufacturer's recommendation, before separating it from the impressions, trimming, and finishing.

Once the master cast (control) was completed, a custom tray was fabricated after four fiducial mark stops were made on the master cast to standardize custom tray positioning during open-tray impression taking (Fig. 1a,b). During custom tray fabrication, two layers of baseplate wax (NeoWax; Dentsply Inc, York, PA, USA) were applied to provide 3 mm of space relief for the impression material. The custom tray, with five holes to accommodate the impression coping guide pins and four mark stops, was fabricated with visible light-curing acrylic resin (Triad Tru-Tray VLC; Dentsply Inc, York, PA, USA). A box for pouring the impression with dental stone was made with addition reaction silicone (Exaflex putty; GC America Inc, Alsip, Il) to create a silicone matrix. This matrix was used for pouring all the impressions, allowing standardization of the shape of the stone casts and for the amount of dental stone used for the pouring.

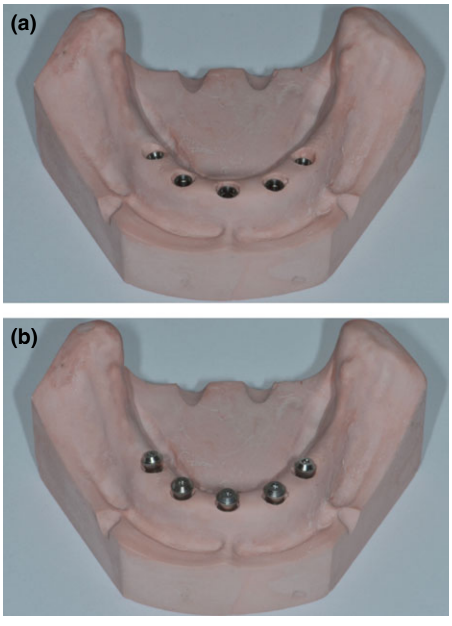

Fig. 1. Master cast (control) (a) implant-level (b) abutment-level.

Conventional implant impression procedures

Prior to the impression, tray adhesive (3M ESPE; Impregum) was applied thinly and evenly into the intaglio surface of the custom tray. The tray adhesive was allowed to dry for 15 min before the impression was made. Polyether impression material (Impregum) was used for all conventional implant impressions. The impressions were made in a controlled-temperature environment (25°C ± 2°C) with a relative humidity of 50%. The mark stops on the master cast served as an index for precise positioning of the custom tray every time. The custom tray was always seated with light finger pressure until the mark stops contacted their respective areas on the master cast. The polyether impression material was allowed to polymerize for 12 min. Four different techniques were used for impression taking: (i) implant-level, splinted technique with visible light-cured resin (Triad gel; Dentsply Inc, York, PA), (ii) implant-level, non-splinted impression technique, (iii) abutment-level, splinted technique with visible light-cured resin (Triad gel; Dentsply Inc, York, PA, USA), and (iv) abutment-level, non-splinted impression technique. Ten implant impressions with polyether material (Impregum) were taken to fabricate 10 implant casts for each technique (n = 10). Standardized pressure was applied over each custom tray while setting, by the help of 1 kg weight.

Splinting materials and technique

The splinting material used was urethane dimethacrylate-based visible light-cured resin (Triad gel; Dentsply Inc, York, PA, USA). Prefabricated resin bars had been made by filling drinking straws with resin (Triad gel) followed by light curing, thus creating resin bars of standardized thickness and shape. The resin bars were stored for 24 h and then used to splint the impression copings together with the aid of additional light-cured resin (Triad gel). The splints were sectioned with a disk and re-connected with minimal amount of visible light-cured resin to compensate for polymerization shrinkage. The splint was left untouched for 5 min (Papaspyridakos et al. 2011, 2012). For the non-splinted technique, the impression copings were not splinted to each other. For the abutment-level impressions, straight multiunit abutments (Multi-Base RC, Straumann) of the same height were torqued on the implants with 35 Ncm. Abutment-level impression copings were connected to the implant abutment platforms and the impression procedures were carried out as described above.

Fabrication of casts from conventional impressions

Standardized pouring techniques were used for the fabrication of all casts. After connection of the implant analogs to the impression copings, low expansion (0.09%) type IV die stone (Silky Rock; Whipmix Corp, Louisville, KY, USA) was mixed. First, the stone was mixed manually with distilled water for 15 s to aid the incorporation of the water and then under vacuum (Vacuum spatulator; Whipmix Corp, Louisville, KY, USA), and an initial pour of stone up to the middle of the analogs was carried out. All of the stone mixes were vibrated before and during the pouring. After 30 min, the second pour of vacuum-mixed die stone was carried out. This double pouring technique minimizes the volumetric expansion of the stone and has been shown to lead in more accurate die casts (Del'Acqua et al. 2008; Papaspyridakos et al. 2012). All impressions were poured after 2 h following impression taking to simulate a reasonable clinical scenario. The stone casts were allowed to set for 1 h, as per manufacturer's recommendation, before separation from the impressions. Subsequently, they were trimmed and finished. All casts were stored at room temperature for 1 week before the measurements. The exact same double pouring technique was used for the fabrication of casts from all the conventional impressions. All impression and pouring procedures were carried out by the same clinician (Fig. 2a,b).

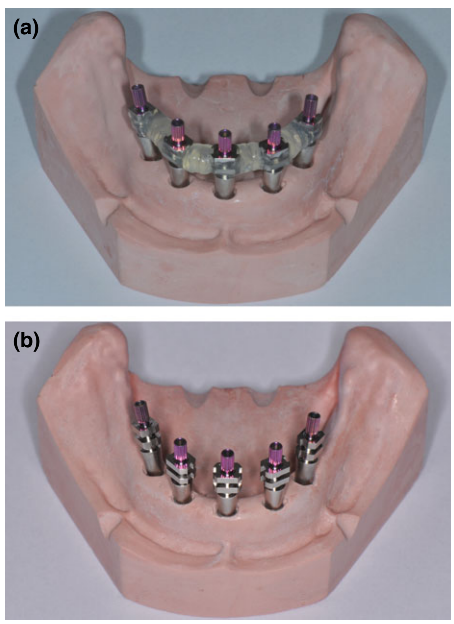

Fig. 2. (a) Splinted implant-level impression. (b) Non-splinted implant-level impression.

Digital implant impression procedures

Following the manufacturer's protocol, 10 repeated digital impressions were taken with a digital intraoral scanner (TRIOS; 3shape, Denmark) at implant level. This digital intraoral scanner uses confocal optical imaging technology to generate digital point cloud surfaces that can be exported as STL datasets and is used for both partial and complete arch intraoral scans.

Polymer implant impression scan bodies (Scan bodies RC; Straumann) were connected to the implants on the master cast (control) by hand tightening. The digital implant impression was gradually captured by scanning the master cast and implant scan bodies with the scanner's handheld wand without spraying powder. The digitally acquired volumes could be viewed on the touch screen during scanning, allowing direct visual feedback to make sure no parts were missing. After the acquisition of ten repeated digital impressions, the digital volumes were exported as STL files for comparison.

Test groups – implant impression techniques

Thus, five test groups of casts were formed, and each group was compared with the control cast as follows:

- *GROUP I* (n = 10): Stone casts generated from the splinted coping impression technique at the implant level (internal connection)
- *GROUP II* (n = 10): Stone casts generated from the non-splinted coping impression technique at the implant level (internal connection)
- *GROUP III* (n = 10): Digital casts generated from the digital impression technique at the implant level (internal connection)
- *GROUP IV* (n = 10): Stone casts generated from the splinted coping impression technique at the abutment level (external connection)
- *GROUP V* (n = 10): Stone casts generated from the non-splinted coping impression technique at the abutment level (external connection)

Digitization of the stone casts

The four test groups of stone casts were digitized for comparison with a high-resolution extraoral scanner at 6-μm precision scanner (IScan D103i; Imetric) as described in previous publications (Bergin et al. 2013; Ender & Mehl 2013). At first, titanium scan bodies (Scan markers; Dentwise, Leuven, Belgium) were placed on the first test cast and digital scanning was performed. Then, the scan bodies were removed and were placed on the second cast for scanning. The same scanning procedures were carried out for all 10 casts of all four test groups. For all digital scans, the same scan bodies were moved from their mandibular corresponding position in cast 1 to cast 10 of each group to eliminate the effect of scan bodies. An operator blinded to the type of casts performed all scanning procedures. The STL digital files were saved.

Accuracy assessment with digital scanning and superimposition

One digital scan of the master cast at the implant level and one scan at the abutment level, with the same high-resolution extraoral scanner at 6-μm precision (IScan D103i; Imetric), were used as control (golden reference) and compared with the scans of the casts of the five test groups produced by digital and conventional impression techniques. To capture the 3D orientation of the implants in each cast and their 3D discrepancies, the digital volumes from the 5 test groups were registered using a surface-based registration algorithm. The 3D deviations were then calculated with superimposition software (Mimics; Materialise, Leuven, Belgium) for data comparison. The study's workflow is shown in Fig. 3.

The terms "trueness" and "precision" represent different measures of accuracy (Ender & Mehl 2013). Trueness is defined as the comparison between a control dataset and a test dataset. The measured deviations between the control dataset and the test dataset determine the accuracy of a scanner. Precision is defined as a comparison between different datasets obtained using the same digital scanner. Such an examination provides information about the repeatability of a scanner. The digital scanning STL datasets from all casts were imported in the computer with dedicated software and superimposed with the dataset from the control cast, respectively. The 2nd parallel implant was used as reference to superimpose the different scanning datasets with the aid of the computer software. The cumulative 3D deviation was calculated, using the mathematical equation $3D = \sqrt{x^2 + y^2 + z^2}$ (Papaspyridakos et al. 2012). Comparisons of all 3D deviations were made between each of the test groups and the control (trueness).

Statistical analysis

All statistical analyses were performed with SAS 9.3 statistical software (SAS Institute, Cary, NC, USA). For estimating the 3D deviations of the test casts, the analysis of variance (ANOVA) and Scheffe's *post hoc* test were used to compare the differences between Group I, Group II, and Group III, and Student's *t*-test was used for testing the difference between Group IV and Group V.

For estimating the difference of each implant between each of the test groups, the nonparametric statistical methods were used. Kruskal–Wallis test was used for comparing the differences between Group I, Group II, and Group III for each implant, and the difference between each test group was further examined by Dunn's *post hoc* analysis. For testing the difference between Group IV and Group V, Wilcoxon's rank-sum test was used for each implant. The level of statistical significance was set at $P < 0.0001$.

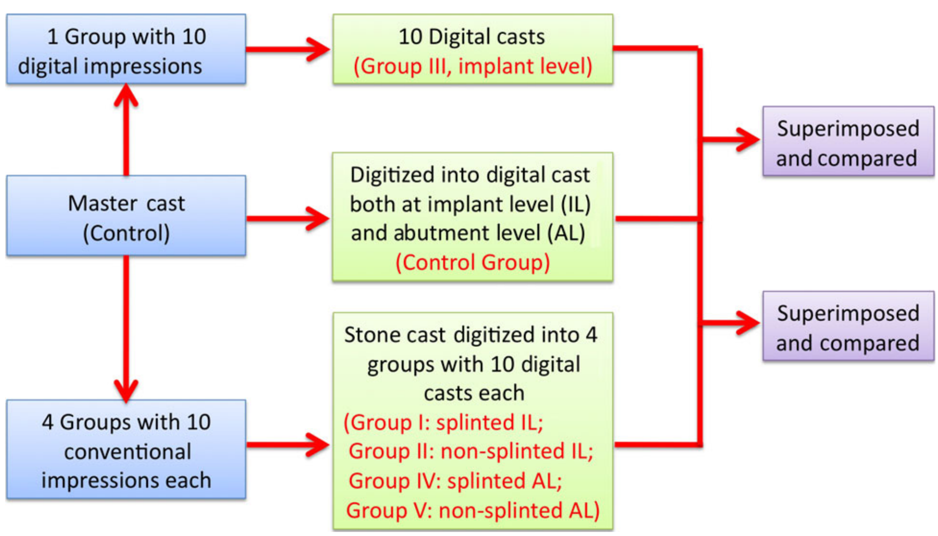

Fig. 3. Study workflow.

Results

The absolute values of 3D deviations from the control cast were calculated and displayed for each test group in Tables 1 and 2. The splinted, implant-level impressions (Group I) showed median 3D (global) deviations of 6 μm for implant 1 (10°), 9 μm for implant 3 (parallel), 5 μm for implant 4 (parallel), and 13 μm for implant 5 (15°). The non-splinted, implant-level impressions (Group II) showed median 3D deviations of 22 μm for implant 1 (10°), 13 μm for implant 3 (parallel), 13 μm for implant 4 (parallel), and 132 μm for implant 5 (15°). The digital impressions (Group III) showed median global deviations of 23 μm for implant 1 (10°), 15 μm for implant 3 (parallel), 8 μm for implant 4 (parallel), and 29 μm for implant 5 (15°).

The splinted, abutment-level impressions (Group IV) showed median 3D deviations of 33 μm for implant 1 (10°), 14 μm for implant 3 (parallel), 12 μm for implant 4 (parallel), and 9 μm for implant 5 (15°). The non-splinted, abutment-level impressions (Group V) showed median 3D deviations of 15 *μm* for implant 1 (10°), 1 *μm* for implant 3 (parallel), 7 *μm* for implant 4 (parallel), and 10 *μm* for implant 5 (15°). The overall mean values of 3D deviation were 8, 45, 19, 17, and 8 *μm* for Groups I to V, respectively.

Significant 3D deviations ($P < 0.0001$) were found between Group II (non-splinted, implant level) and control. No significant difference was found between Groups I (splinted, implant level), III (digital, implant level), IV (splinted, abutment level), and V (non-splinted, abutment level) compared with the control. As a qualitative analysis, the 3D deviations between the test casts and the control cast were illustrated in a color-coded gradient (Fig. 4). When the color-difference maps of the superimposed scans were predominantly green this indicated indicating an exact fit between scans and the reference model; however, red or blue color, indicating positive or negative discrepancies, indicates discrepancies on the fit. The box plots for the median of individual 3D implant deviations are shown in Figs 5 and 6.

Discussion

An accurate implant impression is necessary, to generate an accurate definitive cast which is the milestone for the fabrication of an accurately fitting prosthesis. To overcome some of the limitations with conventional

Table 1. **Measurement and comparison of three-dimensional (3D) deviations (in μm) for Groups I, II, III**

	n	Group I (a)	Group II (b)	Group III (c)	*P*-value†	*Post hoc* test
Overall, Median (IQR)	40	7.42 (5.28–10.88)	17.65 (13.19–76.49)	19.38 (11.54–26.21)	<0.0001	(a) vs. (b) (a) vs. (c)
Implant 1, Median (IQR)	10	5.79 (5.69–5.94)	21.89 (21.84–21.98)	23.39 (23.27–23.47)	<0.0001	(a) vs. (c)
Implant 2, Median (IQR)	10	N/A	N/A	N/A	N/A	
Implant 3, Median (IQR)	10	9.16 (8.99–9.28)	13.00 (12.84–13.21)	15.27 (15.18–15.53)	<0.0001	(a) vs. (c)
Implant 4, Median (IQR)	10	4.70 (4.54–4.81)	13.39 (12.97–13.46)	7.60 (7.54–7.67)	<0.0001	(a) vs. (b)
Implant 5, Median (IQR)	10	12.52 (12.44–12.67)	131.75 (131.6–132.1)	29.02 (28.78–29.15)	<0.0001	(a) vs. (b)
P-value		<0.0001	<0.0001	<0.0001		
Post hoc test		Implant 4 vs. 5	Implant 4 vs. 5	Implant 4 vs. 5		

N/A: implant 2 was used as a reference for superimposition.
IQR: interquartile range.
Statistical significance, P<0.0001.
†The *P*-value is from the Kruskal–Wallis test for each Implant.
Dunn's *post hoc* tests revealed a significant difference between groups.

Table 2. **Measurement and comparison of three-dimensional (3D) deviations (in μm) for Groups IV and V**

	n	Group IV	Group V	*P*-value†
Overall, Median (IQR)	40	13.05 (10.46–23.67)	8.23 (4.01–12.13)	<0.0001
Implant 1, Median (IQR)	10	33.10 (32.93–33.24)	14.59 (14.52–14.76)	0.0002
Implant 2, Median (IQR)	10	N/A	N/A	
Implant 3, Median (IQR)	10	14.31 (13.98–14.49)	1.27 (1.19–1.37)	0.0002
Implant 4, Median (IQR)	10	12.04 (11.86–12.13)	6.91 (6.69–6.96)	0.0002
Implant 5, Median (IQR)	10	8.86 (8.81–9.01)	9.63 (9.37–9.78)	0.0002
P-value		<0.0001	<0.0001	
		Implant 4 vs. 5	Implant 4 vs. 5	

N/A: implant 2 was used as a reference for superimposition.
IQR: interquartile range.
Statistical significance, $P < 0.0001$.
†The *P*-value is from the Wilcoxon's rank-sum test.

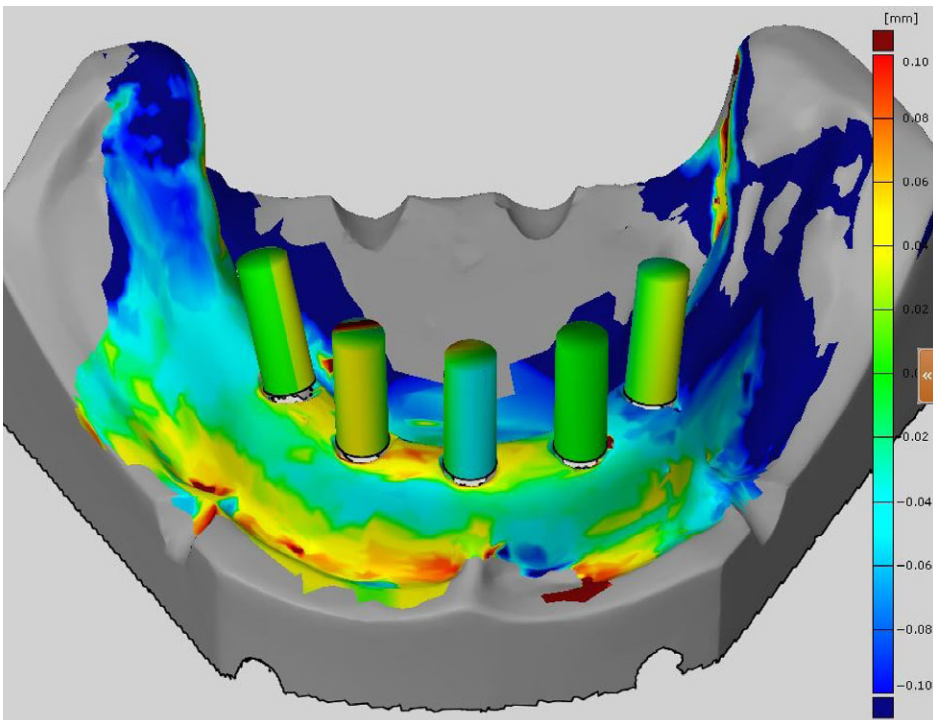

Fig. 4. Color-coded gradient from Group III (digital).

impression techniques, intraoral digital scanning was developed. Digital implant impressions are currently gaining popularity; however, limited scientific data are available in terms of accuracy of this technology (Christensen 2009).

To the authors' knowledge, the present *in vitro* study is the first to directly compare the accuracy of digital vs conventional implant impressions for the completely edentulous patient. The null hypothesis was corroborated. The results of this study indicate that the digital impressions had similar accuracy when compared with the conventional impressions. Prior to the accuracy comparison, the casts generated from conventional impressions had been digitized, similarly described in previous publications to be compared with the digital casts (Bergin et al. 2013; Guth et al. 2013; Kim et al. 2013).

Digital scanning and dedicated software for superimposition of the resultant STL datasets represent an efficient technique to measure and compare the trueness (accuracy) at the microscopic level (Ender & Mehl 2013). Trueness is defined as the proximity of the absolute values of the 3D deviations of each test dataset in relation to the control dataset (Ender & Mehl 2013; Patzelt et al. 2014). For the present study, one parallel implant (the second in the middle) was used during the superimposition procedures to assess the accuracy of implant impressions (Akyalcin et al. 2013; Guth et al. 2013; Papaspyridakos & Lal 2013; Schaefer et al. 2014). The superimposition of STL datasets by best-fit algorithm has been one of the most common methodologies to investigate the accuracy (Guth et al. 2013). Other superimposition techniques include the "least squares method" and the "zero method" (Jemt & Hjalmarsson 2012; Gimenez et al. 2015). The accuracy outcomes may be affected by the digital scanner, the choice of digitization method, the alignment methodology, and the distribution and number of surface data points (Papaspyridakos et al. 2014a).

The findings of the present comparative study corroborated the null hypothesis and show that the accuracy of digital impressions is the same as that of conventional impressions. In regard to the implant level, the digi-

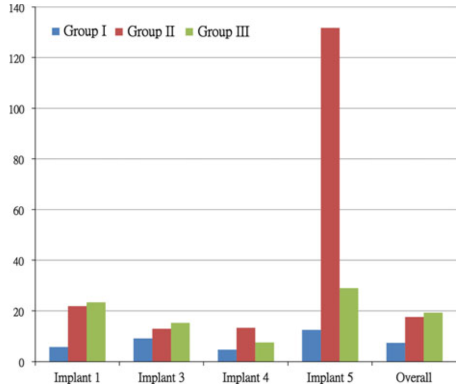

Fig. 5. Implant-level groups: Absolute values of 3-D deviations from the test casts to the reference cast (in μm).

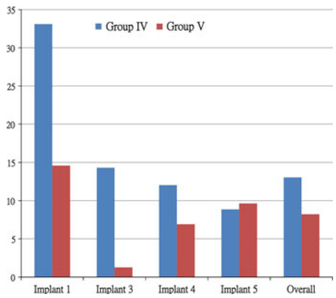

Fig. 6. Abutment-level groups: Absolute values of 3-D deviations from the test casts to the reference cast (in μm).

tal impressions of five mandibular implants resulted in similar accuracy to the splinted, implant-level impressions and both techniques were superior to the non-splinted, implant-level impression technique. The 3D implant deviations with the non-splinted impressions (Group II) had statistically significant differences compared with the control. The most distal implant had a mean deviation of 132 μm from the control, compared with 13 and 29 μm for the splinted (Group I) and the digital impressions (Group III), respectively. These findings are in agreement with the majority of *in vitro* and clinical studies for complete arch implant impressions (Papaspyridakos et al. 2011, 2014a; Stimmelmayr et al. 2012b).

In regard to the abutment level, the 3D deviations for both splinted and non-splinted impressions were similar and did not have statistically significant differences from the control in the present study. This is in agreement with previous *in vitro* studies by Kim et al. and Del'Acqua et al., regarding abutment-level impressions (Kim et al. 2006; Del'Acqua et al. 2008). However, other recent *in vitro* studies have shown different results from the present study and have favoured the splinted technique at the abutment level (Vigolo et al. 2003; Naconecy et al. 2004; Del'Acqua et al. 2010; Avila et al. 2012). The different methodologies of accuracy measurements may have contributed to this discrepancy.

The geometry of the implant connection is an important factor that contributes in maintaining the stability of the implant–prosthesis interface. In regard to internal connection, the impression coping has an intimate fit with the implant which may make withdrawal of the impression more difficult and, therefore, may generate a higher degree of distortion. The connection type (internal connection vs abutment level) seems to affect accuracy because abutment-level impressions had no statistically significant differences from the control, whereas differences were identified for the implant-level, non-splinted impressions from internal connection implants.

The accuracy of digital implant impressions was not affected by the implant angulation of 10° and 15° for completely edentulous patients in the present study. This corroborated the findings of Gimenez et al. with angulations of up to 30°, where the authors reported that implant angulation did not affect the accuracy in a statistically significant rate when the blue light LAVA C.O.S. scanner (active wavefront sampling technology) was used (Gimenez et al. 2015). Additionally, in a duplicate study by the same group with the identical scenario of angulated implants, it was reported that implant angulation of up to 30° did not affect statistically significantly the accuracy of digital impressions when the red light iTero scanner (Align Technology Inc, San Jose, CA, USA) with parallel confocal imaging was used (Gimenez et al. 2014). The common denominator in both studies was that the operator experience may play a role in the accuracy of digital impressions and that a learning curve exists before the clinician gets skillful with the digital impression scanners.

Only a few scientific studies have been published regarding the accuracy of digital impression systems for complete arch scans with prepared teeth for tooth-supported prostheses. Two studies were carried out by the same group of investigators using two digital scanners (CEREC Bluecam & Lava C.O.S.). The complete arch scan involved only three prepared teeth (2 for crowns & 1 for inlay) (Ender & Mehl 2011, 2013). The reported accuracy (trueness) values for the CEREC Bluecam and the Lava C.O.S. were 49 ± 14.2 and 40.3 ± 14.1 μm, respectively. In contrast, accuracy values of conventional complete arch impressions using polyether showed comparable values of 55 ± 21.8 and 61.3 ± 21.8 μm, respectively (Ender & Mehl 2011). Another study conducted by Patzelt et al. scanned a control cast with 14 prepared teeth, using four different commercially available digital scanners (CEREC Bluecam, Lava C.O.S., iTero, Zfx IntraScan). They showed that three of them produced comparably accurate impressions (Patzelt et al. 2014). Mean accuracy values ranged from 38 to 332.9 μm, while one scanner demonstrated unacceptable accuracy. However, it must be mentioned that the Lava C.O.S. scanner is not in the market anymore and has been replaced by 3M True Definition scanner. On the other hand, the CEREC Bluecam is still available, but a newer improved version in the form of CEREC Omnicam is now commercially available (Yuzbasioglu et al. 2014). A recent study by Kim et al. used the iTero scanner with parallel confocal imaging (Align Technology Inc) for complete arch impressions of three prepared teeth and compared the accuracy with conventional impressions (Kim et al. 2013). The results showed that digital impressions achieved comparable accuracy with the conventional ones.

In terms of digital impressions for implant-supported prostheses, there is a paucity of scientific data limited to case reports with single-implant crowns (Lin et al. 2013; Joda & Bragger 2014; Wismeijer et al. 2014). A recent *in vitro* study by Lee et al. investigated the accuracy of digital versus closed-tray impressions for a single-implant scenario (Lee et al. 2014). They reported that the digital impressions had comparable accuracy with the conventional ones. In regard to edentulous jaws and complete arch implant impressions, two recent *in vitro* studies by Gimenez et al. used an edentulous maxilla with six angulated implants and two types of scanners (Lava C.O.S. and iTero, respectively) to assess the accuracy of the digital impression (Gimenez et al. 2015; Gimenez et al. 2014). The results showed accuracy better than 45 and 32 μm in the horizontal plane, respectively, but there were no control groups. Besides the present study, there are no other studies yet comparing the accuracy of digital vs conventional implant impressions for completely edentulous patients.

A clinical study on implant impressions for two implant-supported mandibular overdentures reported that the accuracy of digital impressions with iTero was inferior to conventional ones and should not be recommended clinically until improvements are made (Andriessen et al. 2014). A complete digital workflow in implant dentistry will include the following steps: (i) cone beam computed tomography (CBCT) radiographic examination followed by implant surgical planning with virtual planning software with or without fabrication of surgical template for guided surgery, (ii) digital impression after implant osseointegration, and (iii) CAD/CAM fabrication of the implant prosthesis (Joda & Bragger 2014). Digital impressions include direct intraoral scanning or indirect digitization of casts generated from conventional implant impressions. The resulting STL file form the digital impression enters the production chain and serves as the data for the CAD and subsequent CAM applications in a virtual "working cast-free" process. If needed, a physical cast can be fabricated by rapid prototyping (stereolithography, 3D printing, or milling) from the intraoral digital impression dataset. So far, only two clinical reports have elaborated on the digital workflow for fabrication of complete arch implant prosthesis from impression to delivery (Moreno et al. 2013; Lin et al. 2014).

Previous studies have used other technology including coordinate measuring machine (CMM) and computed tomography for the scanning of the master cast (control) to use that dataset file as the golden reference (Ender & Mehl 2013; Guth et al. 2013). For the present study, an extraoral scanner (IScan D103i; Imetric) with 6 μm precision was used for all digitization procedures, which may be seen as a limitation because other studies have used the CMM with a repeatability of 1 μm. The TRIOS scanner for intraoral impressions has shown acceptable clinical accuracy for single crowns (Schaefer et al. 2014). Another limitation of the present study is that only one implant system was used at both implant and abutment level. Further studies should be carried out with different implant systems and scanners as well before definitive clinical recommendations can be made for treatment of completely edentulous patients.

Digital implant dentistry is gaining increasing popularity and is showcasing good potential; however further studies are needed to assess and compare the clinical accuracy of digital versus conventional implant impression techniques for both partially and completely edentulous patients. Additionally, the complete digital workflow from planning to definitive rehabilitation should be assessed and compared with the conventional one in terms of time efficiency, learning curve, accuracy, and economical aspects. In clinical practice, combined utilization of both the digital and the conventional approach may present with additional advantages specific to the treatment of each case.

Conclusions

Under the limitations of the present *in vitro* study, the following conclusions may be drawn:

- The accuracy of digital impressions was not different than the implant-level, splinted impressions for completely edentulous patients and both more accurate than the implant-level, non-splinted impressions.
- The implant-level, splinted impressions were more accurate than the non-splinted conventional impressions for completely edentulous patients.
- The accuracy of abutment-level, splinted impressions was not different than the non-splinted impressions for completely edentulous patients.
- The accuracy of implant impressions is not affected by the implant angulation up to 15° for completely edentulous patients. The connection type seems to affect accuracy because abutment-level impressions had no statistically significant differences from the control, whereas differences were identified for the implant-level, non-splinted impressions.

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